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NOISE CONTROL FOR QUALITY OF LIFE

Mapping sound pressure levels on continental scales using a geospatial sound model

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ABSTRACT

Local acoustical conditions measured by ANSI type 1 sound level meters are influenced by events and processes ranging from soft animal vocalizations at 10 meter scales to thunder and transportation noise at 10-100 km scales. Because many wildlife habitats, geological processes, and anthropogenic impacts occur on a regional scale, acoustical analyses must encompass a similar extent. Using long-term sound pressure level measurements from hundreds of sites across the contiguous United States, geospatial models have been developed to predict sound levels. These models do not directly apply the physics of sound propagation or characteristics of individual sound sources. Instead, these geospatial sound models incorporate spatial representations of biological, geophysical, climatic, and anthropogenic factors to assess expected contributions to the existing sound pressure level from both anthropogenic and natural sources. These methods enable mapping of sound pressure levels at regional and national scales.

Keywords: geospatial, ambient, map

1. INTRODUCTION

Noise is an increasingly pervasive factor throughout the U. S. National Park system [1]. Since 1970, road traffic has tripled in the United States, and air traffic, both passenger and freight, has grown faster than surface transportation [2]. Multinational scientific studies of public health and noise have revealed that a significant fraction of the United States and European populations is suffering chronic health consequences from noise exposure [3-5].

Noise impacts are not limited to developed areas, or people alone [1,6,7]. One aircraft can broadcast audible noise up to 40 km from its flight path, and a loud truck or motorcycle can cast noise up to 10 km from a road if there is no intervening terrain. Many protected natural areas enjoy extremely low background sound levels, and distant noise sources degrade otherwise outstanding listening conditions for wildlife and park visitors. The bioacoustic sounds present in an environment are good indicators of ecosystem health [8] and the pervasiveness of noise is a threat to ecological integrity. Anthropogenic noise can have direct consequences to wildlife fitness by impairing

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communication, elevating stress levels, and reducing breeding success [2, 9, 10].

The distribution, development, and abundance of transportation and other human activities calls for noise monitoring and management capabilities that span regional and national scales. These large spatial scales can render direct monitoring efforts infeasible, though noise propagation models are a practical alternative that offer options for exploring hypothetical scenarios. Noise mapping efforts are increasing rapidly; a recent European Union directive has motivated the production of continental scale noise maps considering anthropogenic sources [11]. The U. S. lags behind Europe in this effort, although the importance of a continental scale analysis has been recognized and exploratory maps of noise exposure have been generated [5]. Noise propagation models have also been used to explore the spatial scales at which wildlife responses to noise might occur [7].

In order to address facilitate comprehension, proactive management, and effective mitigation of noise pollution on regional scales, additional tools are needed. Noise impacts are always evaluated in the context of ambient conditions, so some method of predicting what background sound levels would be in the absence of noise is required. Natural sounds can significantly influence overall sound pressure level, and determine the capacity of the natural environment to mask incoming noise. For example, high ambient levels can result from wind which can be an important consideration in assessing the noise annoyance of wind turbines [12]. Alternative methods for predicting noise levels in terms of generic descriptors of human density and activity are needed for scenarios that involve an uncountable number of noise sources, or noise sources whose numbers and spatial distributions not have been quantified.

This paper shows how a geospatial sound model [13] can be used to assess acoustic conditions on large scales, focusing on the contiguous United States (CONUS). Section 2 introduces the geospatial modeling approach and details revisions made for expansion over a large, acoustically diverse area. Section 3 presents the predicted acoustical conditions across the contiguous United States. In addition to existing levels, a natural scenario and the relative anthropogenic impact was calculated.

2. GEOSPATIAL SOUND MODELING

A geospatial sound model is an empirical regression model that relates measured acoustic metrics to geospatial data including biogeophysical, climatic, and anthropogenic variables [13]. The approach assumes an independent acoustic field at every discrete location due to the interaction between multiple geospatial variables. A given explanatory variable can represent one or more sources, propagation effects, or both. For the results discussed herein, relationships between the acoustic and geospatial data were discovered and applied using Random Forest, a tree-based machine learning algorithm [14]. Methods have been devised to determine the geospatial data relevant to an individual acoustic metric and one-third octave band, to interpret the resulting models, and to predict acoustical conditions across large area [13].

2.1 Expanding to national scales

Initial geospatial models were designed to explain the acoustical conditions in US National Parks, the many of which are undeveloped or contain designated wilderness. The performance of any modeling approach is limited by the quality of the available training data. Significant revisions to the explanatory variables and observations that make up the training data have been made to address the scope of the contiguous United States model discussed in this paper. In the random forest approach, rare observations of extreme levels (either very quiet or very loud) without discriminating features captured by the explanatory variables were lumped into terminal nodes of the decision trees with less extreme observations. The result was a regression towards the mean and the levels of very loud observations were under predicted and very quiet observations were over predicted.

The original variable set included 69 potential explanatory variables in 7 categories: location, climatic, landcover, hydrology, anthropogenic, temporal, and equipment [13]. In an effort to further distinguish acoustical conditions at sites, new explanatory variables and variations of previous variables have been derived and introduced to the modeling process. The revised variable set contained 109 variables. The new variables included dew point, distance to railroads and multiple airport types, population density, physical access, expanded land use classes, and a low elevation wind data set [15]. Land use variables were derived for areas of analysis with radii of 200 m and 5 km. Population density was calculated over an area of 50 km radius for each point. These variables were evaluated as per previously established methods.

Despite the informational content of any available explanatory variables, it is reasonable to question whether a sparse sample of empirical measurements sufficiently represents the acoustical diversity of the contiguous United States. Previous work [13] showed anthropogenic sources to be the strongest driver of sound pressure levels, even though the measurement site locations were in national parks. Studies of community noise [16] in urban areas have found a linear relationship between population density and the magnitude of noise SPL, specifically day night sound level (DNL). Therefore, training data from densely populated places like New York City were needed to provide an upper bound for existing sound pressure levels across the contiguous United States. A lower bound was available from extremely quiet areas like Great Sand Dunes National Park, where the equipment self-noise floor can be dominant for much of the measurement period (8 dBA).

To address the acoustic diversity of the contiguous United States, 34 measurements from 28 cities have been added to the pool of measurements from National Park sites. The city measurements, which also include suburban and rural areas, represent acoustical conditions in developed areas. While the duration of measurements in natural areas are typically 25 days or longer to obtain statistics representative of the entire season, the city measurements were over a 24 hour period only. This is in accordance with the assumption that sound levels in developed areas are relatively consistent given the dominating contribution from human activity. See Schomer [16] for more information on the data set. Furthermore, measurements from 19 geographically unique sites located in U.S. National Parks have been added to further strengthen the geospatial sound model. The revised training set had a total of 353 observations at 244 geographically unique locations. A map of the site locations appears in Figure 1.

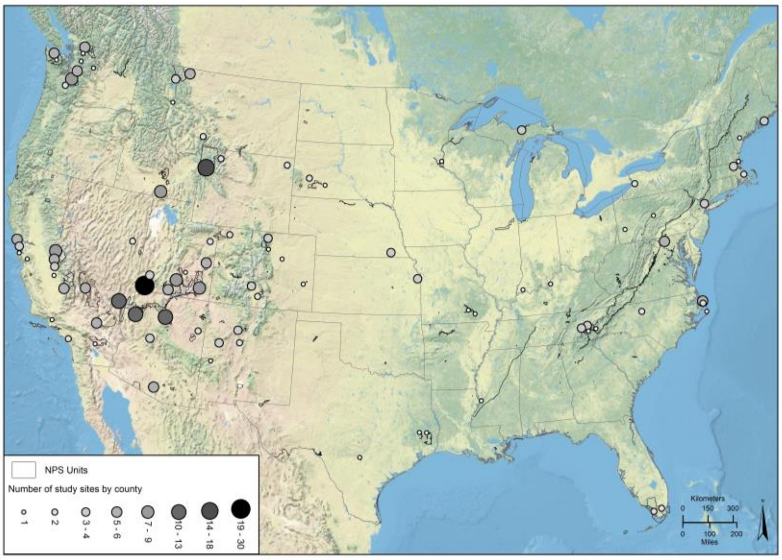

Figure 1 – Locations of the sites used to train the geospatial sound models.

2.2 Structure of the CONUS geospatial sound model

Geospatial models for the existing A-weighted L_{10}, L_{50}, and L_{90} were derived using the revised training data and methods described in [13]. Full spectrum A-weighted exceedance statistics were the focus of this work for multiple reasons, with availability of data chiefly among them. The L_{eq} is an extremely rich metric in that it accounts for all energy present over the integration period, regardless of event duration. Because both a loud transient and quieter noise of long duration will be incorporated into the L_{eq}, it is useful for assessing the total impact using a single number. However, because many signals can have an equivalent L_{eq}, the single metric can be difficult to interpret. Exceedance statistics discriminate events by ordering data and otherwise ignoring the magnitude. For example, the L_{10} is the loudest 10% of the data and therefore tends to represent the loud transients only. Because the L_{50} is the level exceeded half of the time, it is a fair representation of expected conditions.

The number of important explanatory variables for the revised L_{10}, L_{50}, and L_{90} models were 84, 72 and 36 respectively. This agrees with previous work that suggested that high exceedance levels are a complex blend of many sources whereas background levels are unaffected by transients and dominated by a few persistent sources. Table A.1 (see appendix) lists all the explanatory variables that were identified in the optimal L_{50} model, which is the focus of section 3. See [15] for more detail concerning the original data layers and how the metrics were derived.

The seven most important variables for three acoustic metrics appear below in Table 1. Overall, the table is almost equally divided between anthropogenic and biogeophysical variables, however, the variables at the top of the list have the most influence which then diminishes rapidly. Anthropogenic variables contribute disproportionately to the loudest existing levels (L_{10}) whereas background levels in most places are explained by more biogeophysical information such as climate and vegetation. Elevation, which appears prominently in all three models, is correlated with many natural phenomena, including moisture content, temperature, and the presence of animal and plant species. It is likely that elevation also bears some relation to human activity; for example, coastal areas are disproportionately prized for residential, commercial, and industrial interests.

Table 1 – The seven most influential explanatory variables for each acoustic metric.

Importance	L_{10}, dBA	L_{50}, dBA	L_{90}, dBA
1	*Developed200m*	*Industrial5km*	*Elevation*
2	*RecCon200m*	*Shrubland5000m*	*PhysicalAccess*
3	*PhysicalAccess*	*Forest200m*	*Forest200m*
4	*TDEWAvgSummer*	*PhysicalAccess*	*Shrubland5000m*
5	*DistHighAirports*	*RecCon200m*	*RddMajor5km*
6	*Elevation*	*Elevation*	*Evergreen200m*
7	*FlightFreq25Mile*	*Developed200m*	*PPTNorms*

2.3 Performance of the CONUS geospatial sound model

The ability of the revised geospatial sound models (GSM) to calculate A-weighted exceedance levels was compared to null models in terms of root mean square error (RMSE), median absolute deviation (MAD), and the percent variation explained. All measures were calculated using an exhaustive leave-one-out cross validation [13]. The results for the full CONUS data set, park subset, and city subset appear below in Tables 2, 3, and 4 respectively.

Table 2 –Performance of the geospatial sound model compared to null models, CONUS data set.

Metric	GSM, RMSE	Null, RMSE	GSM, MAD	Null, MAD	Explained, %
L_{10}, dBA	4.75	9.01	2.54	5.7	72.26
L_{50}, dBA	5.11	9.62	2.95	6.6	71.74
L_{90}, dBA	4.91	9.46	2.72	6.5	73.07

Table 3 – Performance of the geospatial sound model compared to null models, city data set only.

Metric	GSM, RMSE	Null, RMSE	GSM, MAD	Null, MAD	Explained, %
L_{10}, dBA	7.64	8.88	4.44	5.7	26.03
L_{50}, dBA	7.24	8.11	3.32	4.62	20.3
L_{90}, dBA	5.85	6.7	3.78	3.6	23.79

Table 4 – Performance of the geospatial sound model compared to null models, park data set only.

Metric	GSM, RMSE	Null, RMSE	GSM, MAD	Null, MAD	Explained, %
L_{10}, dBA	4.33	7.5	2.45	4.9	66.74
L_{50}, dBA	4.83	8.25	2.88	5.8	65.72
L_{90}, dBA	4.8	8.3	2.66	5.4	66.59

The higher percentage of explained variation for the total set is due to the high accuracy over the majority of observations in tandem with the increased variation in the training set, which contained two populations: the city sites in loud developed areas and park sites in quieter undeveloped areas. Individually, the null model statistics reveal similar variation in SPL for the park and city sites; however, the accuracy of park site predictions is vastly superior to the city sites. The strongest factor is likely the relative sample sizes: 319 observations of park sites versus 34 observations of city sites. The numerous park observations educate the random forest algorithm on a greater variety of conditions than the city observations. Because the relatively few city sites are among the loudest observations in the training data, they also suffer from a regression towards the mean. To a lesser extent, the short duration of the city measurements may have contributed to the increased scatter relative to park observations.

Given that a convenient linear model has been established to predict DNL in developed areas given population density alone [16], it is worthwhile to question whether the additional complexity of the geospatial model is worthwhile. Table 5 shows a RMSE comparison between the linear model and the geospatial model. In this case the training data was limited to the 34 city sites (referred to as the volunteer data in [16]) and a null model is included for reference. The geospatial model shows a moderate decrease in error relative to the linear model, although the difference is likely to increase with sample size. It is interesting to note that population density, although ranked highly, was not useful enough to be included in the optimal geospatial model. Instead, the list of variables identified as important included only (from most important to least): *Transportation5km*, *DistRoadsMajor*, *Industrial5km*, *RddWeightedPt*, and *ExurbanHigh5km*.

Table 5 – Performance of the geospatial sound model compared to linear and null models, city data set only

	Null, RMSE	LM, RMSE	Explained, %	GSM, RMSE	Explained, %
DNL	8.82	7.55	26.75	6.76	41.36

3. PROJECTION ACROSS THE CONTIGUOUS UNITED STATES

3.1 Existing sound pressure levels

All the explanatory variables identified as important were accumulated across the contiguous United States at a resolution of 270m, resulting in 183,300,975 points across a rectangular study area 4615 km x 2896 km. Variables were resampled from their native resolution as necessary with ArcGIS tools. At each grid point, the L_{50} geospatial model was used to predict the full spectrum A-weighted existing sound pressure level. The time of year was set to midsummer. The resulting map of existing sound pressure levels appears below in Figure 2; the color axis uses Jenks natural breaks classification. This prediction represents the A-weighted SPL exceeded half of time during a typical summer day over the last 10 years.

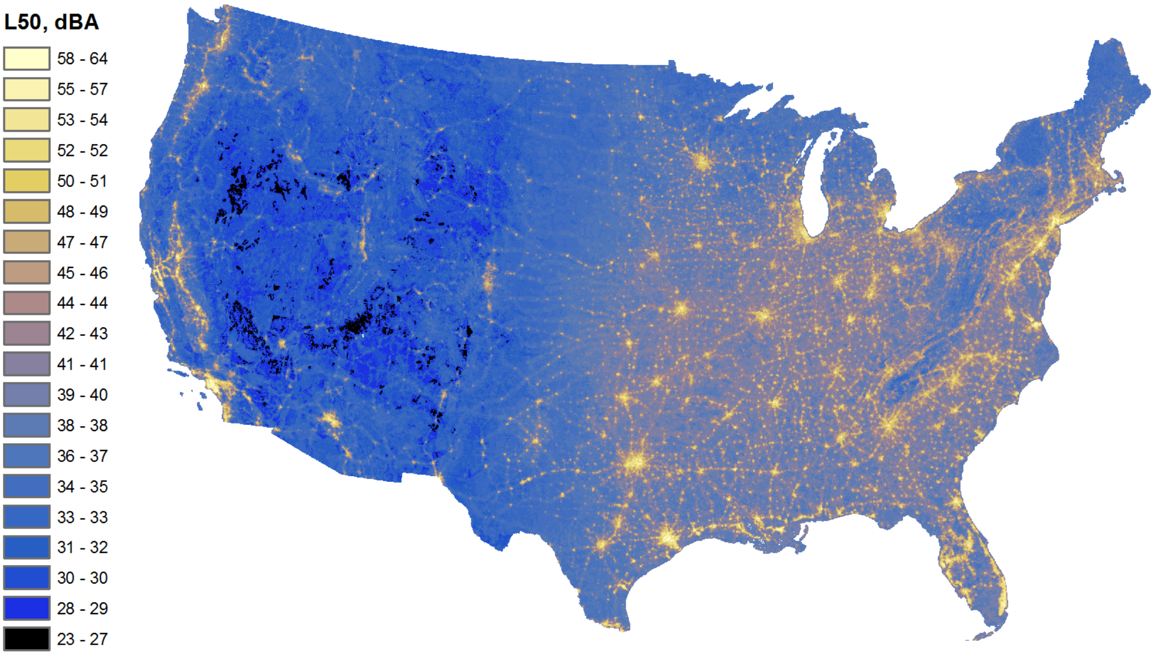

Figure 2 – Existing A-weighted L_{50} as predicted by the geospatial sound model.

From this broad perspective, the most apparent features are the location of major US cities and the interstate highway system that connects them. These are the loudest areas of the country, and the pattern is driven most strongly by the explanatory variables: *Industrial5km*, *PhysicalAccess*, and *RecCon200m* (Table A.1). The explanatory power of some quantities is less clear than others; *Industrial5km* could be accounting for the magnitude and type of road traffic as much as noise from factories. Air traffic is relatively infrequent and has less influence on the L_{50}, but is geographically widespread. 23% of area has an existing L_{50} above 40 dBA and 1% of the area has an existing L_{50} above 50 dBA. The range of L_{50} existing agrees well with previous estimates [4].

The map bears a striking resemblance to recent Visible Infrared Imaging Radiometer Suite (VIIRS) data from NASA[17], although roads have somewhat more widespread influence in the acoustic domain. Furthermore, whereas undeveloped areas may be absent of radiated light they are not absent of sound. Biological and geophysical sources are also included in the existing SPL, although the spatial signatures of natural sources are overshadowed in much of the country at this resolution. The lowest levels are experienced by conserved lands in the western United States.

3.2 Natural sound pressure levels

The existing sound pressure level is the condition as measured; it includes all acoustic energy. Many of the important explanatory variables clearly represent anthropogenic activity; these are identified in Table A.1. A natural scenario was created by systematically manipulating the explanatory variable set at each grid point. For example, the proportion of developed landcover in a 200m radius (*Developed200m*) was set to 0 and the distance to the nearest major road (*DistRoadsMajor*) was set to the maximum value of the training data. The resulting map of the A-weighted L_{50} due to natural sources only appears below in Figure 3. Overall, the range of expected levels is much reduced compared to the existing sound pressure levels. In a natural environment, the average summertime L_{50} is not expected to exceed 41 dBA.

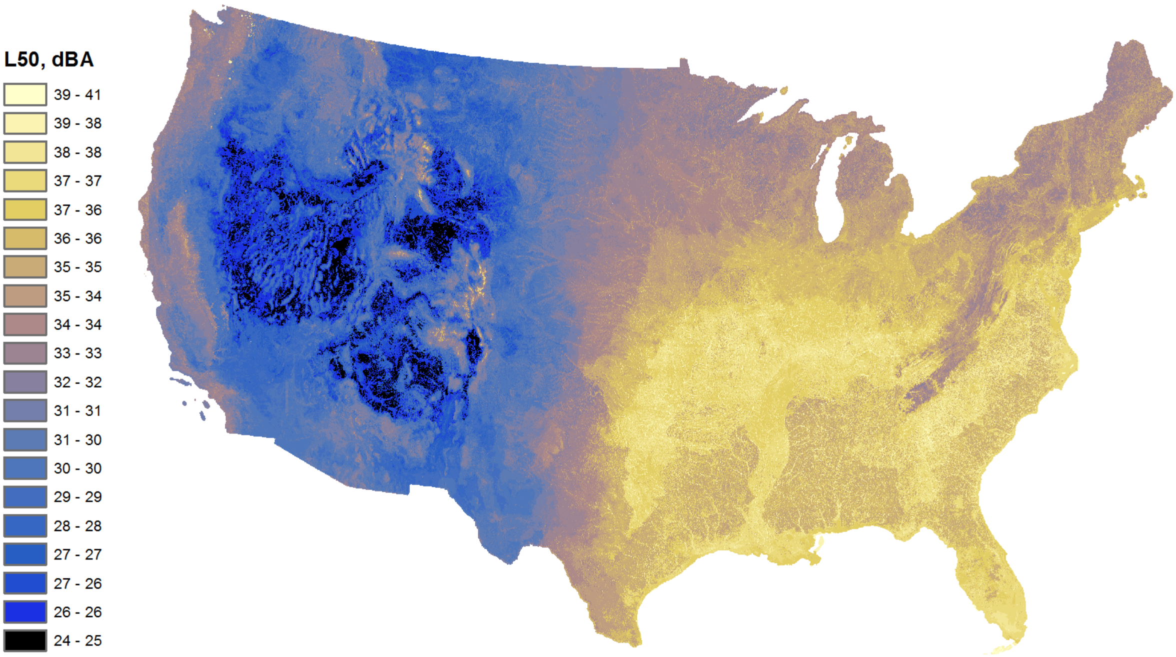

Figure 3 – The expected A-weighted L_{50} due to natural sources only.

On a global scale, the presence of life and consequently sound is driven primarily by latitude and moisture. Likewise, climate has a dominant effect on the magnitude of natural sound in the contiguous United States. The highest sound pressure levels are found in the southeast, mostly a result of flowing water, wind induced vegetation sounds, precipitation, and bioacoustic energy. The area surrounding the Mississippi river stands out, characterized by wetland landcover, low elevation, and proximity to high order streams. Climate, and the resulting precipitation, open water, and landcover, largely defines the acoustical conditions across the United States. The eastern half of the country is characterized by wetlands and deciduous forest cover, which, in addition to wind induced vegetation sounds, also supports more insects and wildlife than other landcover types. The quietest places in the west are areas of dry, high elevation shrubland and barren, flat terrain.

3.3 Impact of anthropogenic sources

A measure of impact L_I can be defined as the difference between the existing, L_E, and natural, L_N, sound pressure levels:

$$L_I = L_E - L_N \tag{1}$$

L_I indicates how much anthropogenic noise raises the existing L_{50} sound pressure level. In roughly 2% of the CONUS area, the L_{50} of the natural scenario exceeded the existing level and the impact was artificially set to 0. This likely stems from artifacts of the process although it is possible that anthropogenic presence inhibits biological activity and natural levels are truly louder in some cases. Given particular combinations of signal and noise spectra, a noise intrusion may be audible when it is as much as 10 dB quieter than the background level, however, A-weighting discards frequency information. Noise may be interpreted as “noticeable” when its A-weighted sound level equals the A-weighted background level [5]. An impact of 3dB suggests that anthropogenic noise is noticeable at least 50% of the hour or more.

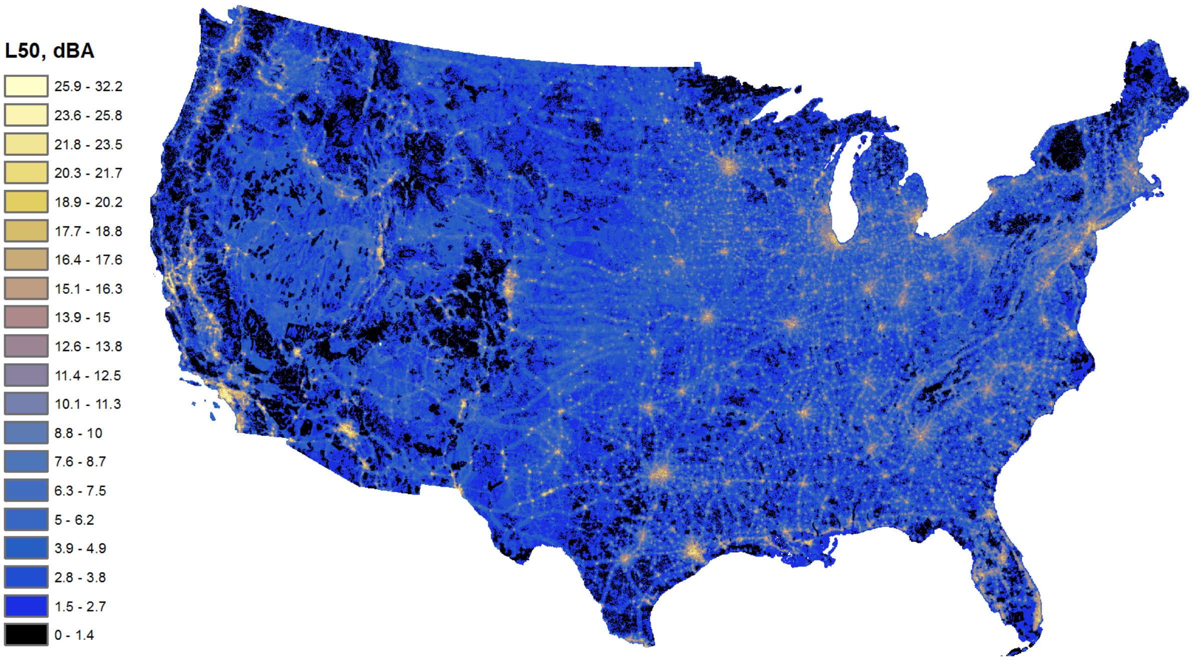

Figure 4 – The impact of anthropogenic activity across the contiguous United States.

A map of the anthropogenic impact in terms of the L_{50} SPL appears in Figure 4. Densely populated and industrialized areas suffer the highest impact, elevating the existing level up to 32 dBA. While the eastern United States is the most heavily developed, almost the entire country is affected by anthropogenic noise. Unfortunately, the quietest areas are the most susceptible to noise. Whereas high altitude aircraft may not be noticed in a bustling urban area, the noise adds appreciably to the stillness of an otherwise quiet wilderness. Pervasive flight traffic coupled with an extensive road network eliminates natural quiet across almost the entire country. Only 12% of the country has an impact of 1.4 dBA or less. There are some large concentrated areas of low impact, notably the Adirondack Mountains in northern New York state and portions of the Rocky Mountain Range in western states. However, most of the low impact areas are fragmented by transportation networks.

In general, protected lands and lands not suitable for agriculture have a reduced level of impact. Roughly half of the low impact area occurs in designated recreational or conserved lands. However, boundaries are not sufficient alone. Figure 5 shows a portion of the L_{50} impact map zoomed in to an area surrounding Tucson, Arizona. The green lines identify the boundaries of Saguaro National Park (boundaries of other conserved lands are not shown).

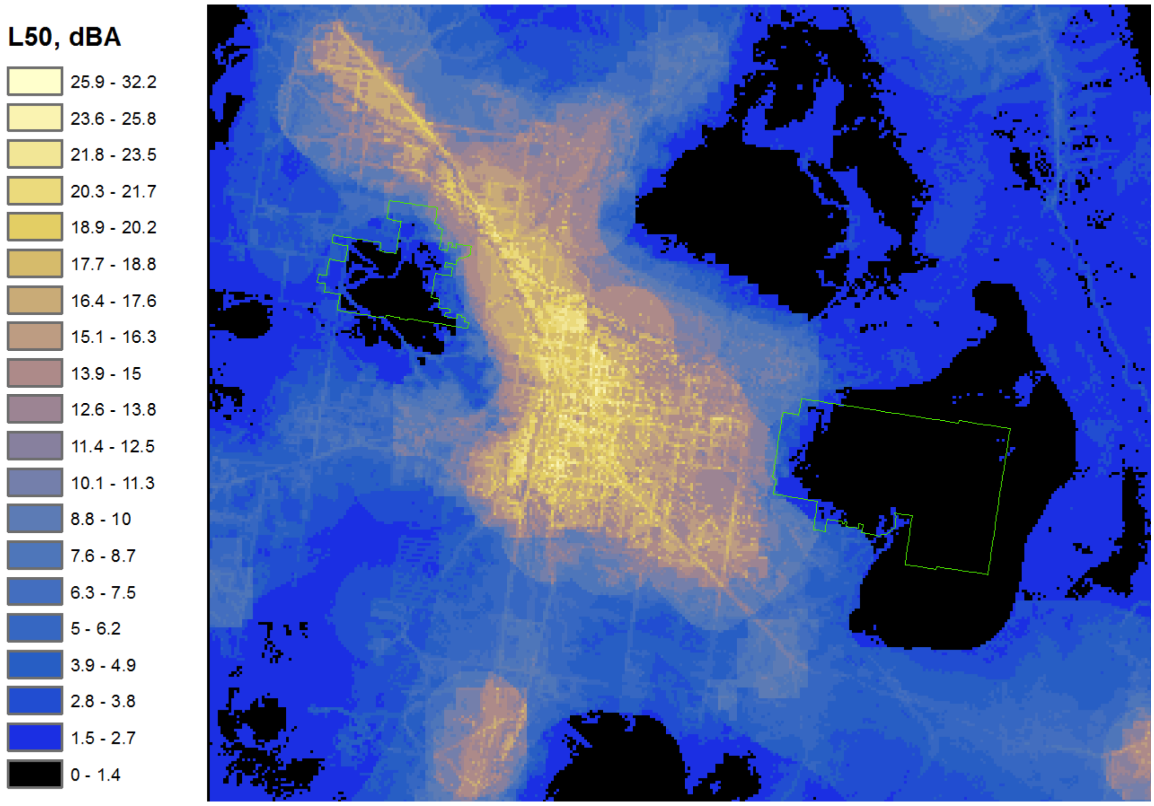

Figure 5 – The impact of anthropogenic activity across southern Arizona. Saguaro National Park boundaries appear in green.

4. CONCLUSION

This paper presented expected acoustical conditions across the contiguous United States. This is a large area with a diverse mix of natural and anthropogenic sound sources. The natural sound sources are often overshadowed by the prevalence of anthropogenic activity. The maps were produced using a geospatial sound model which utilized the random forest algorithm to regress empirical acoustical data against explanatory variables derived from nationally available geospatial data layers. The model essentially connects the dots between hundreds of observations in a variety of habitats. There is no doubt that some areas experience acoustical conditions contrary to model predictions. The highest error is expected in the tails of the distribution, i.e. the loudest levels are under predicted and the quietest levels are over predicted. However, many trends are well explained. It should be noted that the geospatial modeling framework complements existing tools for explicit noise modeling. It is possible that very accurate assessments of acoustic conditions can be achieved by including noise layers from an independent effort, leaving a geospatial model to account for any residual noise.

A measure of impact relative to a natural scenario was calculated. This was a conservative estimate; an unweighted or otherwise more sensitive acoustic metric would show much more pervasive impacts across a wider area. For those who have lived in an urban area and visited remote or protected lands, the scaling of noise magnitude with development is of no surprise. However, the quantity of land with a relatively low level of impact is striking. Furthermore, the locations of the areas that are left suggest that ecological systems are heavily fragmented. Understanding the current extent of noise pollution across the country and the factors that will drive it in the future is a vital step towards proactive management. Monitoring remains essential to track conditions and test the effectiveness of mitigations over time. However, conventional noise impact studies have a need for spatially accurate reference conditions. By establishing a natural baseline, a critical gap has been filled that allows for understanding field data and estimating a proxy when such measurements are not possible.

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APPENDIX

Table A.1 – Explanatory variables included in the optimal L_{50} model. Type specifies A for anthropogenic quantities that were manipulated to generate the natural scenario.

Importance	Name	Description	Type
1	*Industrial5km*	Proportion of industrialized landcover over 5 km radius.	A
2	*Shrubland5000m*	Proportion of shrubland landcover over 5 km radius.	N
3	*Forest200m*	Proportion of forest landcover over 200 m radius.	N
4	*PhysicalAccess*	Physical Accessibility Value, defined by distance from road network and hillslope.	A
5	*RecCon200m*	Proportion of land designated recreational or conserved over 200 m radius.	A

6	*Elevation*	Elevation above sea level, m.	N
7	*Developed200m*	Proportion of developed landcover over 200 m radius.	A
8	*PPTSummer*	10 year average summer precipitation, mm.	N
9	*TDEWAvgSummer*	10 year average summer dewpoint temperature, °C.	N
10	*Evergreen200m*	Proportion of evergreen forest landcover over 200m radius.	N
11	*RddMajor5km*	Sum of major road density over 5 km radius.	A
12	*DistRoadsMajor*	Distance to nearest major road, m.	A
13	*RecCon5km*	Proportion of land designated as recreation/conservation over a 5 km radius.	A
14	*TMINAvgSummer*	10 year average summer minimum temperature, °C.	N
15	*Forest5000m*	Proportion of forest landcover over 5 km radius.	N
16	*TDEWNorms*	10 year average yearly dewpoint temperature, °C.	N
17	*DistHighAirports*	Distance to nearest airport with greater than 1 million enplanements, m.	A
18	*PPTNorms*	10 year average yearly precipitation, mm.	N
19	*Evergreen5000m*	Proportion of evergreen forest landcover over 5 km radius.	N
20	*DistStrahlerCalgt3*	Distance to flowline with a stream order greater than 3, m.	N
21	*Built5km*	Proportion of land classified as built over a 5 km radius.	A
22	*Shrubland200m*	Proportion of shrubland landcover over200 m radius.	N
23	*Built200m*	Proportion of land classified as built over a 200 m radius.	A
24	*Longitude*	Longitude, degrees.	N
25	*UrbanLow5km*	Proportion of land classified as residential urban over a 5 km radius.	A
26	*TMINNorms*	10 year average summer minimum temperature, °C.	N
27	*DistRoadsAll*	Distance to nearest road, m.	A
28	*DistanceRailroads*	Eucilidean distance to nearest major railroad, m.	A
29	*Wetlands5000m*	Proportion of wetland landcover over 5 km radius.	N
30	*FlightFreq25Mile*	Total weekly flight observations over a 25 mile radius.	A
31	*Deciduous5000m*	Proportion of deciduous forest landcover over 5 km radius.	N
32	*TMAXNorms*	10 year average summer maximum temperature, °C.	N
33	*PopDensity2010_50km*	Human population density over a 50 km radius.	A
34	*PPTWinter*	10 year average winter precipitation, mm.	N
35	*ndBA*	Noise floor of measurement equipment, dBA	N
36	*UrbanHigh5km*	Proportion of land classified as built residential urban high over a 5 km radius.	A
37	*ExurbanHigh5km*	Proportion of land classified as built exurban high over a 5 km radius.	A
38	*DistAirportsAllMotorized*	Distance to nearest motorized airport, seaplane base, heliport, or ultralight, m.	A
39	*DistStrahlerCalgt4*	Distance to flowline with a stream order greater than 4, m.	N
40	*RddMajorPt*	Density of major roads at grid point, km/km2.	A
41	*Suburban5km*	Proportion of land classified as built residential suburban high over a 5 km radius.	A
42	*DistAirportsSeaplane*	Distance to nearest seaplane base only, m.	A
43	*Transportation5km*	Proportion of land classified as built transportation over a 5 km radius.	A
44	*Barren5000m*	Proportion of barren landcover over 5 km radius.	N
45	*TDEWAvgWinter*	10 year average winter dewpoint temperature, °C.	N
46	*Grazing5km*	Proportion of land classified as extractive grazing over a 5 km radius.	A
47	*DistanceMilitary*	Distance to nearest military flight path, m.	A
48	*DistModerateAirports*	Distance to nearest airport with greater than 250,000 enplanements, m.	A
49	*DistStrahlerCalgt1*	Distance to flowline with a stream order greater than 1, m.	N
50	*TMINAvgWinter*	10 year average winter minimum temperature, °C.	N
51	*Herbaceous200m*	Proportion of herbaceous landcover over 200m radius.	N
52	*Commercial5km*	Proportion of land classified as built commercial over a 5 km radius.	A
53	*TMAXAvgSummer*	10 year average summer maximum temperature, °C.	N

54	*DistanceCoast*	Distance to coast line, m.	N
55	*Snow5000m*	Proportion of snow landcover over 5 km radius.	N
56	*Latitude*	Latitude, degrees.	N
57	*Mixed5000m*	Proportion of mixed forest landcover over 5 km radius.	N
58	*WaterNat5km*	Proportion of land classified as natural water over a 5 km radius.	N
59	*TMAXAvgWinter*	10 year average winter maximum temperature, °C.	N
60	*WaterHum5km*	Proportion of land classified as human modified water over a 5 km radius.	A
61	*Cultivated5000m*	Proportion of cultivated landcover over 5 km radius.	A
62	*Slope*	Rate of change of elevation at grid point, degrees.	N
63	*Wilderness*	Sum of area designated wilderness over a 10 mile radius.	A
64	*ExurbanLow5km*	Proportion of land classified as built exurban low over a 5 km radius.	A
65	*Wet5km*	Proportion of wetland landcover over 5 km radius.	N
66	*Snow200m*	Proportion of snow landcover over 200 m radius.	N
67	*dayLength*	Average length of day during measurement.	N
68	*Cultivated200m*	Proportion of cultivated landcover over 200 m radius.	A
69	*Extractive200m*	Proportion of land classified as extractive (e.g. timber, mining) over a 200 m radius.	A
70	*DistHeliports*	Distance to nearest heliport only, m.	A
71	*DistLowAirports*	Distance to nearest airport with greater than 5,000 enplanements, m.	A
72	*circDayY*	Time of year (summer/winter), radians.	N